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Dated 23 October 2003

29OCT02 E759129-1 D01914
P01/7700 0.00-0225048.8

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1. Your reference	MJN/67780/000	
2. Patent application number *(The Patent Office will fill in this part)*	28 OCT 2002	0225048.8
3. Full name, address and postcode of the or of each applicant *(underline all surnames)*	ABB Offshore Systems Limited 2 High Street Nailsea Bristol BS48 1BS	
07692221001 Patents ADP number *(if you know it)*		
If the applicant is a corporate body, give the country/state of its incorporation	United Kingdom (GB)	
4. Title of the invention	A METHOD AND INSTALLATION FOR MONITORING MICROSEISMIC EVENTS	
5. Name of your agent *(if you have one)* "Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	PAGE HARGRAVE Southgate, Whitefriars Lewins Mead BRISTOL BS1 2NT	
Patents ADP number *(if you know it)*	05996483001	

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number	Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application	Number of earlier application	Date of filing *(day / month / year)*

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:* *a) any applicant named in part 3 is not an inventor, or* *b) there is an inventor who is not named as an applicant, or* *c) any named applicant is a corporate body.* *See note (d))*	Yes

9. Enter the number of sheets for any of the following items you are filing with this form. Do not count copies of the same document

Continuation sheets of this form	-
Description	9
Claim(s)	3
Abstract	1
Drawing(s)	3

10. If you are also filing any of the following, state how many against each item.

Priority documents	-
Translations of priority documents	-
Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	Four
Request for preliminary examination and search *(Patents Form 9/77)*	One
Request for substantive examination *(Patents Form 10/77)*	-
Any other documents *(please specify)*	-

11. I/We request the grant of a patent on the basis of this application.

Signature PAGE HARGRAVE Date 25/10/02

12. Name and daytime telephone number of person to contact in the United Kingdom — Mr M J Newstead (0117) 927 6634

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DUPLICATE

A METHOD AND INSTALLATION FOR MONITORING MICROSEISMIC EVENTS

The present invention relates to a method and installation for monitoring microseismic events.

Microseismic events are of interest as they can provide information about fluid extraction from a hydrocarbon production reservoir or injection of fluid into the reservoir. The removal of oil or gas from the reservoir leads to stress equalisation processes, which can cause rock failure in the reservoir itself or in other underground cavities in the area, which in turn leads to an elastic wave propagating away from the source. Depending on the source mechanism, different proportions of the acoustic energy are shared between compressional (P-wave) and shear (S-wave) waves. During the waves transit, the P and S waves travel through the interposing vibrational media, such as different rock strata. Each rock type that the waves pass through has different P and S wave velocities and attenuation. By using a suitable arrangement of microseismic sensors (for example by using a triaxial arrangement of geophones or accelerometers and analysing the time lag between arrival of the P and S waves), it is possible via known techniques to locate the approximate location of the microseismic event.

While microseismic monitoring is well developed in some fields, for example that of mining and similar rock engineering activities, most microseismic work in the petroleum industry has to date been of a temporary nature, eg. monitoring short-term operations such as fracturings or cuttings, or experimental nature, eg. pilots for permanent systems. In most cases, where one or more production wells have already been constructed, measurements are conducted by locating one or more microseismic sensors inside one or more of the production wells.

In order to carry out a scan for microseismic events, it is important to identify a large number of signals in order to ensure that the data collected is correctly interpreted and applied to the reservoir management. Thus, where the microseismic sensors are located

inside a production well, it normally becomes necessary to suspend production because, during operation, the production flow through the well tubing causes a relatively large amount of noise, which will swamp the microseismic signals which are, by comparison, inherently small. Without a good signal to noise ratio the number of microseismic signals detected reduces and with this goes speed and confidence of interpretation of microseismic events. Furthermore, noise can affect the event localisation accuracy and hence result in an unclear understanding of the results being obtained.

If production is not suspended, only those signals large enough to stand out above the background noise will be usable for the event localisation. This presents a serious problem, because, on the one hand, if production is not suspended it may take days or even weeks for sufficient numbers of signals to be obtained in order to obtain statistically relevant information, while on the other suspending production is a costly interruption for the oil company. Thus, it is in the interest of the petroleum industry to obtain a method of readily obtaining information about the effect of the extraction process on the reservoir while extraction is in progress.

The only permanent production designed sensor array tool that is currently available is that produced by Createch Industrie, of 91882 Massy, France. The latter's effectiveness is limited when in close proximity to the production tubing of a well because, as explained above, of the reduction in the number of events detectable over and above the background fluid flow noise. Likewise, determining the correct arrival time of P and S waves also becomes subject to errors.

US Patent No. 6,049,508 discloses a method of improving the chance of determining a significant microseismic event by avoiding spurious data from events directly connected with mechanical well operation, such as valve openings and closures. The method uses one or more sensors, such as geophones and hydrophones, and at least one reference pick-up, placed in contact with the production casing. However, it does not consider the difficulties posed by background flow noise.

According to the present invention from one aspect, there is provided a method of monitoring microseismic events in a hydrocarbon production reservoir provided with a well comprising inner production tubing and an outer casing, said method comprising:

a) providing two or more microseismic sensors adjacent the outer casing of a well; and

b) processing the output of said sensors in order to provide said sensors with a directional response comprising a reduced sensitivity to sound coming from the direction of the production tubing, such that the ability of said sensors to detect microseismic signals over the background noise generated by fluid flow inside said production tubing is enhanced.

Preferably, step (b) comprises providing said sensors with a cardioid response.

According to the present invention from another aspect, there is provided a method of monitoring microseismic events in a hydrocarbon production reservoir provided with a well comprising inner production tubing and an outer casing, said method comprising:

a) providing one or more microseismic sensors adjacent the well casing of a well;

b) providing one or more microseismic sensors between the production tubing and the sensors located adjacent the casing; and

c) processing the output of the sensors nearer the tubing in conjunction with the output of the sensors adjacent the casing such that the ability of the sensors adjacent the casing to detect microseismic signals over the background noise generated by fluid flow inside said production tubing is enhanced.

According to the present invention from another aspect, there is provided a method of monitoring microseismic events in a hydrocarbon production reservoir provided with a well comprising inner production tubing and an outer casing, said method comprising:

a) providing one or more microseismic sensors adjacent the well casing of a well; and

b) providing increased sound insulation between said sensors and the production tubing such that the ability of said sensors to detect microseismic signals over the background noise generated by fluid flow inside said production tubing is enhanced.

Optionally, some or all of the above methods of monitoring for microseismic events may be combined, in order to further improve the ability of the sensors to detect microseismic signals over the background fluid flow noise. Where microseismic monitoring is to be conducted using sensors installed in more than one well, one or more of the above methods may be employed in each of said wells.

According to the present invention from another aspect, there is provided an installation for monitoring microseismic events in a hydrocarbon production reservoir provided with a well comprising inner production tubing and an outer casing, said installation comprising one or more microseismic sensors adjacent the well casing of the well and means for processing the output of said sensors in order to provide said sensors with a directional response comprising a reduced sensitivity to sound coming from the direction of the production tubing, such that the ability of said sensors to detect microseismic signals over the background noise generated by fluid flow inside said production tubing is enhanced.

According to the present invention from another aspect, there is provide an installation for monitoring microseismic events in a hydrocarbon production reservoir provided with a well comprising inner production tubing and an outer casing, said installation comprising one or more microseismic sensors adjacent the casing of the well, one or more microseismic sensors between the production tubing and the sensors located adjacent the casing of said well, and means for processing the output of the sensors nearer the tubing in conjunction with the output of the sensors adjacent the casing such that the ability of the sensors adjacent the casing to detect microseismic signals over the background noise generated by fluid flow inside said production tubing is enhanced.

According to the present invention from another aspect, there is provided an installation

for monitoring microseismic events in a hydrocarbon production reservoir provided with a well comprising inner production tubing and an outer casing, said installation comprising one or more microseismic sensors adjacent the casing of the well and increased sound insulation between said sensors and the production tubing such that the ability of said sensors to detect microseismic signals over the background noise generated by fluid flow inside said production tubing is enhanced.

Optionally, the features of one of the above installations for monitoring for microseismic events may be combined with the features of one or both of the other installations, in order to further enhance the sensors abilities to detect microseismic signals over the background fluid flow noise.

As discussed above, where sensors are to be installed in production wells, sensor placement close to the flow-generated noise is inevitable. Thus a means of reducing the flow-generated noise acting on these sensors, and thus enhancing their ability to detect a microseismic event, is required.

Generically speaking, a number of different methods are possible in order to reduce the amount of noise received by a sensor. Noise reduction techniques can, broadly speaking, be divided into "active" and "passive" techniques.

Passive techniques involve insulating the sensor against the potential source of noise, for example by changes in cross-sectional area/material property leading to an increase in reflection/scattering, and/or adding an elastomeric inter-layer. In the context of attempting to reduce the amount of fluid flow noise reaching one or more sensors located against a well casing, solutions such as placing sound-absorbent material on the sensor housing on the side facing the flow noise, or surrounding the sensors with acoustic foam filled airspace, all involve passive attenuation of the fluid flow noise.

Active techniques consist of active noise control, beam-forming/null-steering. Both methods use signal processing to improve the signal to noise ratio, which in the context of

the present invention means increasing the microseismic signal to flow noise ratio, such that the ability of the sensors to pick out the desired signals over the background noise is enhanced. These techniques will be explained more fully below, with reference to the following drawings.

How active and passive techniques are applied differs fundamentally. In the present context, since the creation of regions of quiet around the sensors is not of concern, the active techniques are applied to the signals only. In physical terms, all that is required is that the sensors be placed in the appropriate positions to ensure that the active techniques can be applied effectively. By comparison, passive techniques cannot easily be applied once the sensors have been positioned in the completed production well and so must usually be engineered in the design of the installation, for example by making suitable modifications to the sensor array housing, production tubing, well casing or fluid surrounding the production tubing.

Since passive techniques have a tendency to be more effective at higher frequencies and active techniques more effective at lower frequencies, a combination of both will in many cases be beneficial, in order to provide broadband attenuation of the noise signal. In some cases once the likely attenuation versus frequency for each type of active technique has been determined, the precise form and location that of passive attenuation that will be beneficial will be apparent, and thus an appropriate combination can then be easily decided upon. In some cases a combination of several types of one active and passive techniques may prove helpful (ie. a combination of active noise control, beam-forming/null-steering, and more than one type of insulation).

Embodiments of the invention will now be described, by way of example, with reference to accompanying drawings, in which:

Fig. 1 is a simplified vertical section through a length of production well illustrating an installation for monitoring microseismic events;

Fig.2 is a simplified vertical section through a length of production well illustrating an alternative installation for monitoring microseismic events;

Fig.3 is a graph charting the polar response, at various discrete frequencies, of a sensor having a cardioid response; and

Fig.4 is a graph charting the response versus frequency, at various discrete angles, of the same sensor.

Fig.1 shows, in simplified form, a vertical section of a length of production well, comprising a length of production tubing 1, surrounded by a fluid filled annulus 2 and well casing 3. In active production, fluid extracted from the hydrocarbon reservoir flows through the production tubing in the direction of arrow 4. A first pair of microseismic sensors 5 is mounted on the inside of the well casing 3, and a second pair of microseismic sensors 6 is mounted on the outside of the production tubing 1 facing the casing mounted sensors 5 and at approximately the same height. The signal outputs of the casing mounted sensors 5 and tubing mounted sensors 6 are connected to a data processing apparatus (not shown), which is preferably located topside. The data processing apparatus is adapted to simultaneously process the signal outputs of the casing 5 and tubing 6 mounted sensors, utilising active noise control (ANC) techniques in order to improve the microseismic signal to fluid noise ratio.

ANC involves distinguishing a signal from the background noise at the frequency range of interest. It is most effective in simple cases, for example where the background noise originates from a slowly varying, periodic, noise sources from reciprocating engines and at low frequencies. If the source is periodic then it is possible to measure the background noise over one period, and generate the inverse and the appropriate transfer function. The sample rate is synchronised with the engines' rotation. The noise consists of the fundamental and a number of harmonics which are measured by a force transducer placed in series with the engine mounting points and the cancelling source (vibrator).

Where the noise source is flow noise transmitted from the production tubing of an active well, the noise will not be so readily distinguishable from the microseismic signal. However, the presence of sensors 6 mounted against the production tubing allows the noise signal up-stream, ie. closer to the noise source, from the casing mounted sensors 5 to be measured. By estimating the noise at the tubing mounted sensors 6, the transfer function between the tubing mounted sensors 6 and casing mounted sensors 5 (based on the expected noise path between the sensors, as indicated on Fig.1 by arrow 7), and the time for sound to travel between the tubing 6 and casing 5 mounted sensors, it is then possible for the data processing apparatus to subtract the estimated flow noise at the casing mounted sensors 5 sensors from the output of the casing mounted sensors, thereby resulting in an improved ability to detect microseismic events during active production.

Fig.2 shows, again in simplified form, a vertical section of a length of production well, with the production tubing, fluid filled annulus and casing bearing the same reference numbers as before. In the alternative installation shown, only casing mounted sensors 5 are required, with the topside data processing apparatus being programmed to process the signal outputs of the sensors 5 utilising beam forming/null steering techniques, in order to improve the microseismic signal to fluid noise ratio.

Beam forming involves processing the signal outputs of a minimum of two sensors and applying a phase shift or time delay of one relative to the other in order to provide each sensor with a directional response in which the sensitivity of the sensor to sound is reduced in one or more directions, the angle over which sensitivity is substantially maintained being referred to as the sensor's beam and the angle over which sensitivity is substantially reduced being referred to as the null or beam minima. Null-steering involves then rotating the sensor's beam until the null is pointed in the direction in which sound is to ignored.

Thus, in the embodiment illustrated in Fig.2, the data processor operates to maximise the signal to noise ratio by forming an appropriate directional response for each casing sensor 6, and then rotating the sensor's beam such that each sensor's null is pointed in the direction of the production tubing 1. It should be noted that it is not necessary that the

casing mounted sensors 5 be directly adjacent each other, as sensor spacing will affect the final sensitivity of the sensors, with a trade-off of noise reduction against signal reduction being necessary.

Where omni-directional casing mounted sensors 5 are used, it is possible, using beam-forming, to convert their response from omni-directional to cardioid (ie. to use beam-forming to create a cardioid beam). Referring now to Figs.3 and 4, Fig.3 shows the polar response of a sensor having a cardioid response, at various frequencies, while Fig.4 charts the change in response versus frequency of the same sensor at various angles. As the diagrams shown in Figs.3 and 4 represent in-air acoustics, the actual response obtainable by casing sensors in the production well environment may in some respects be quantitatively different in some respects, but in qualitative terms the same type of response should be obtainable. As both figures clearly show, the response of the sensor remains flat between + and - 90 degrees except at high frequencies (above 10 kHz), while the response of the sensor in the 180 degree direction is significantly reduced, particularly in the 1 to 2 kHz range.

Thus, if the casing sensors 6 are provided with such a cardioid response, orientated such that the production tubing lies at null position (180 degrees in the case of the response illustrated in Figs.3 and 4), then it is clear that significantly less flow noise will be picked up by the sensors (particularly in the frequency ranges where attenuation at 180 degrees is significant). At the same time, while there will be some attenuation of microseismic signals originating from the 180 degree direction, the ability of the sensors to pick up microseismic signals originating from the + or - 90 degree region will be largely unaffected, though at high frequencies some attenuation may occur as compared to what would be achieved if beam forming techniques had not been applied. Thus, overall the signal to noise ratio will be substantially improved.

CLAIMS:

1. A method of monitoring microseismic events in a hydrocarbon production reservoir provided with a well comprising inner production tubing and an outer casing, said method comprising:

   a) providing two or more microseismic sensors adjacent the outer casing of a well; and

   b) processing the output of said sensors in order to provide said sensors with a directional response comprising a reduced sensitivity to noise coming from the direction of the production tubing, such that the ability of said sensors to detect microseismic signals over the background noise generated by fluid flow inside said production tubing is enhanced.

2. A method according to claim 1, wherein step (b) comprises providing said sensors with a cardioid response.

3. A method according to claim 1 or 2, wherein microseismic sensors are also provided between the production tubing and the sensors located adjacent the casing, the output of the sensors nearer the tubing being processed in conjunction with the output of the sensors adjacent the casing in order to further enhance the ability of the sensors adjacent the casing to detect microseismic signals over the fluid flow noise.

4. A method according to any preceding claim, wherein increased sound insulation is provided between the casing sensors and the production tubing in order to further enhance the ability of the sensors adjacent the casing to detect microseismic signals over the fluid flow noise.

5. A method of monitoring microseismic events in a hydrocarbon production reservoir provided with a well comprising inner production tubing and an outer casing, said

method comprising:

a) providing one or more microseismic sensors adjacent the well casing of a well;

b) providing one or more microseismic sensors between the production tubing and the sensors located adjacent the casing; and

c) processing the output of the sensors nearer the tubing in conjunction with the output of the sensors adjacent the casing such that the ability of the sensors adjacent the casing to detect microseismic signals over the background noise generated by fluid flow inside said production tubing is enhanced.

6. A method according to claim 5, wherein increased sound insulation is provided between the casing sensors and the production tubing in order to further enhance the ability of the sensors adjacent the casing to detect microseismic signals over the fluid flow noise.

7. A method of monitoring microseismic events in a hydrocarbon production reservoir provided with a well comprising inner production tubing and an outer casing, said method comprising:

a) providing one or more microseismic sensors adjacent the well casing of a well; and

b) providing increased sound insulation between said sensors and the production tubing such that the ability of said sensors to detect microseismic signals over the background noise generated by fluid flow inside said production tubing is enhanced.

8. An installation for monitoring microseismic events in a hydrocarbon production reservoir provided with a well comprising inner production tubing and an outer casing, said installation comprising one or more microseismic sensors adjacent the

well casing of the well and means for processing the output of said sensors in order to provide said sensors with a directional response comprising a reduced sensitivity to noise coming from the direction of the production tubing, such that the ability of said sensors to detect microseismic signals over the background noise generated by fluid flow inside said production tubing is enhanced.

9. An installation for monitoring microseismic events in a hydrocarbon production reservoir provided with a well comprising inner production tubing and an outer casing, said installation comprising one or more microseismic sensors adjacent the casing of the well, one or more microseismic sensors between the production tubing and the sensors located adjacent the casing of said well, and means for processing the output of the sensors nearer the tubing in conjunction with the output of the sensors adjacent the casing such that the ability of the sensors adjacent the casing to detect microseismic signals over the background noise generated by fluid flow inside said production tubing is enhanced.

10. An installation for monitoring microseismic events in a hydrocarbon production reservoir provided with a well comprising inner production tubing and an outer casing, said installation comprising one or more microseismic sensors adjacent the casing of the well and increased sound insulation between said sensors and the production tubing such that the ability of said sensors to detect microseismic signals over the background noise generated by fluid flow inside said production tubing is enhanced.

11. A method of monitoring microseismic events in a hydrocarbon production reservoir substantially as hereinbefore described with reference to Figures 1, 2, 3 and/or 4.

12. An installation for monitoring microseismic events substantially as hereinbefore described with reference to Figures 1, 2, 3 and/or 4.

ABSTRACT

A method of monitoring microseismic events in a hydrocarbon production reservoir provided with a well comprising inner production tubing (1) and an outer casing (13), said method comprising providing one or more microseismic sensors (5) in contact with the well casing of the well, and taking steps to enhance the ability of said sensors to detect microseismic signals over the background noise generated by fluid flow inside said production tubing is enhanced. An installation suitable for carrying out such a method is also disclosed.

(Fig. 1)

FIG. 1

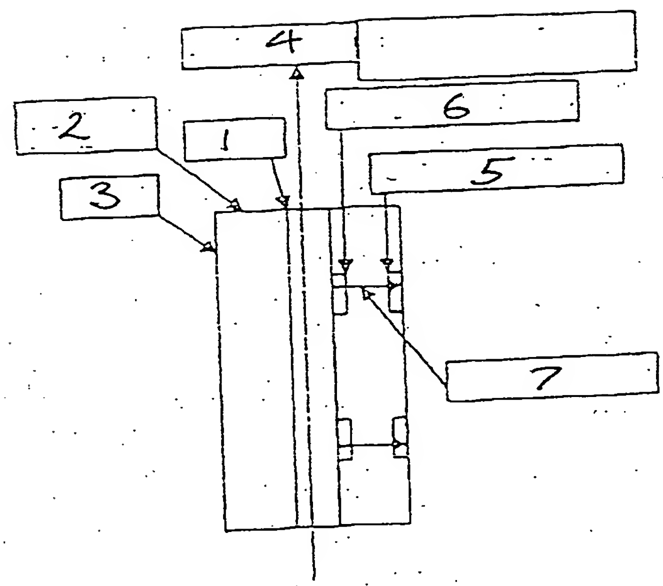


FIG. 2

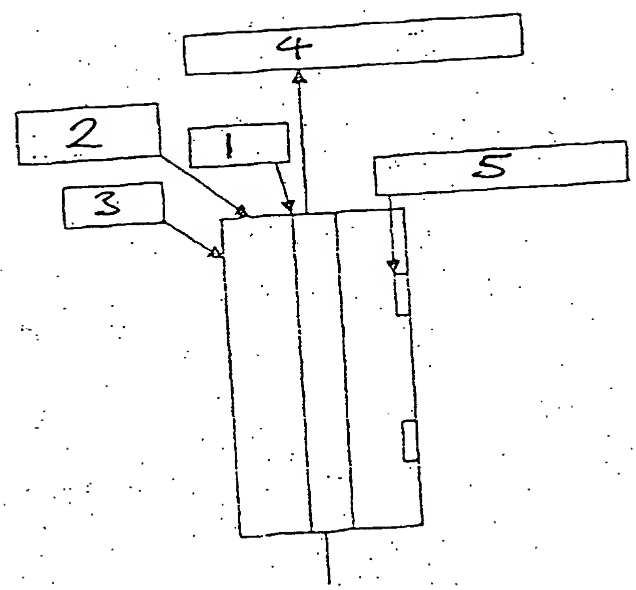
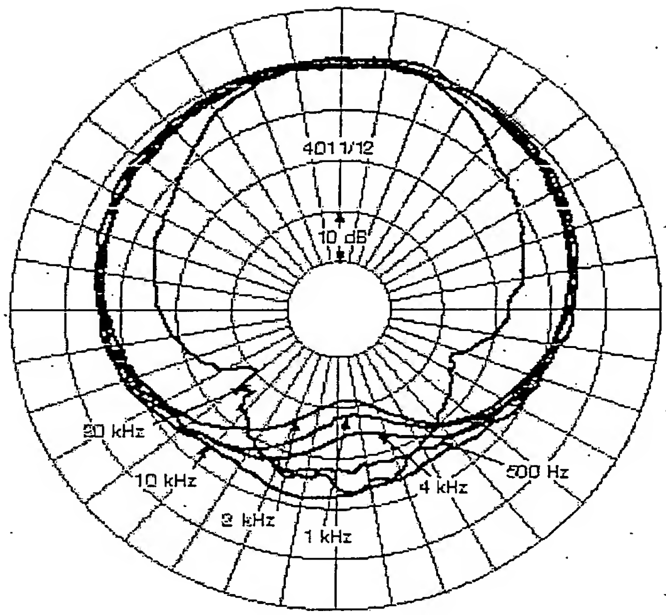


Fig.3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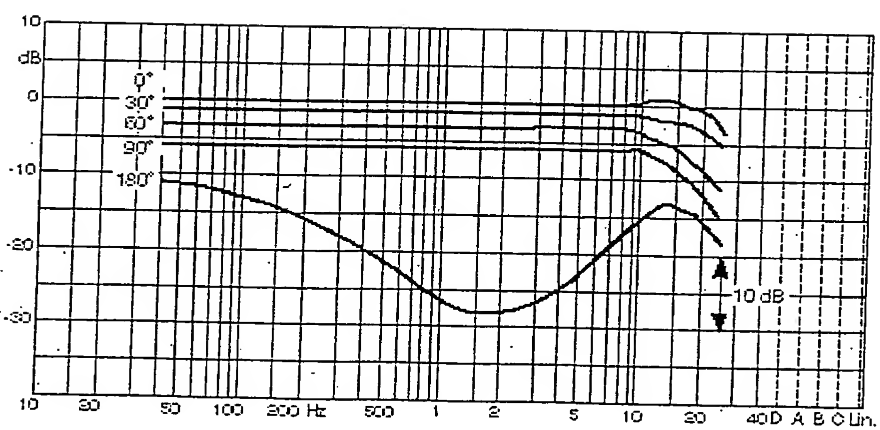
500 Hz

Fig.4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